

HAPTIC DEVICES HAVING MULTIPLE OPERATIONAL MODES INCLUDING AT LEAST ONE RESONANT MODE

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

[0001] This application is continuation of U.S. patent application Ser. No. 10/792,279, filed Mar. 4, 2004, entitled, "Haptic Devices Having Multiple Operational Modes Including At Least One Resonant Mode" which is a continuation-in-part and claims priority to U.S. patent application Ser. No. 10/301,809, entitled "Haptic Feedback Using Rotary Harmonic Moving Mass" and filed Nov. 22, 2002; and U.S. Patent Application No. 60/375,930, entitled "Haptic Feedback Using Rotary Harmonic Moving Mass" and filed Apr. 25, 2002.

TECHNICAL FIELD

[0002] The subject matter relates to a haptic feedback device having multiple operational modes including multiple resonant modes.

BACKGROUND

[0003] Generally, electro-mechanical transducers exhibit a level of power consumption that may be higher than desired. Furthermore, such electro-mechanical transducers may not be able to produce haptic feedback of a desired magnitude or bandwidth due to space constraints.

[0004] What is needed is an electro-mechanical transducer that is configured to produce vibrotactile feedback having a relatively high magnitude and/or an adjustable bandwidth. Additionally, it would be desirable to have an electro-mechanical transducer that can generate haptic feedback having relatively low energy consumption.

OVERVIEW

[0005] An electronic device and method of operating comprises a housing; a base coupled to the housing; and an electro-mechanical transducer coupled to the base, the electro-mechanical transducer configured to operate in a resonant mode and output a haptic effect upon receiving a drive signal at a predetermined drive frequency. In an embodiment, the electro-mechanical transducer further comprises a plurality of electro-mechanical transducers, each electro-mechanical transducer configured to operate in its respective resonant mode and output a respective haptic effect upon receiving a drive signal having a predetermined drive frequency. Alternatively or additionally, the electro-mechanical transducer further comprises a plurality of spaced apart electro-mechanical devices coupled thereto in a serial fashion between a first end proximal to the base and a second end distal to the base. In an embodiment, at least one mass is located a different predetermined distance from the base than a mass of another electro-mechanical device in the plurality. In an embodiment, at least one mass has a weight different than a mass of another electro-mechanical device in the plurality. In an embodiment, the drive frequency of the drive signal applied to two or more of the electro-mechanical transducers in the plurality has a substantially same value. In an embodiment, the drive frequency of the drive signal applied to at least one electro-

mechanical transducer in the plurality is at a higher order of the resonant frequency of another electro-mechanical transducer in the plurality.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 is a system block diagram of an electro-mechanical transducer, according to an embodiment.

[0007] FIG. 2 shows a perspective view of an electro-mechanical device according to an embodiment.

[0008] FIG. 3 shows a perspective view of an electro-mechanical transducer according to an embodiment.

[0009] FIG. 4 shows a perspective view of an electro-mechanical transducer according to another embodiment.

[0010] FIG. 5 shows a perspective view of an electro-mechanical transducer in a parallel arrangement, according to an embodiment.

[0011] FIG. 6 illustrates a plot of a gain profile for a single resonant mode output from single electro-mechanical transducer according to one embodiment.

[0012] FIG. 7 illustrates a plot of a gain profile for multiple resonant modes output by an electro-mechanical transducer according to an embodiment.

[0013] FIG. 8 shows a perspective view of an electro-mechanical transducer in a series arrangement according to another embodiment.

[0014] FIG. 9 shows a side view of an electro-mechanical transducer shown in FIG. 8 in a rest position.

[0015] FIG. 10 illustrates the electro-mechanical transducer according to the embodiment depicted in FIG. 8 operating in a first resonant mode.

[0016] FIG. 11 illustrates the electro-mechanical transducer according to the embodiment depicted in FIG. 8 operating in a second resonant mode.

[0017] FIG. 12 illustrates the electro-mechanical transducer according to the embodiment depicted in FIG. 8 operating in a third resonant mode.

[0018] FIG. 13 is a flow chart illustrating a method for producing an operational mode of an electro-mechanical transducer according to an embodiment.

DETAILED DESCRIPTION

[0019] An apparatus comprises a signal source, a driver and an electro-mechanical transducer having a cantilever. The signal source is configured to output a haptic feedback signal. The driver is configured to receive the haptic feedback signal and output a drive signal. The electro-mechanical transducer has a cantilever and is configured to receive the drive signal. The electro-mechanical transducer is configured to have a set of operational modes. Each operational mode from the set of operational modes has at least one resonant mode from a set of resonant modes.

[0020] In one embodiment, electro-mechanical devices are used in an electro-mechanical transducer that is configured to output haptic feedback in an operational mode having one or more resonant modes. The electro-mechanical transducer is also configured to have multiple operational modes. Such a device can produce diverse and robust haptic feedback that can exhibit relatively low power consumption in a space-efficient manner. Although many embodiments described herein relate to using cantilevers as resonant structures, analogous devices are also possible. For example, such resonant structures can use acoustic cavities, membranes, mass-springs, wheel-torsional springs, and/or other structures capable of exhibiting mechanical resonance. Some embodiment, for example, can have a combination of different types of structure capable of exhibiting mechanical resonance.